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AEROSOL TECHNOLOGY OVERVIEW AND BIBLIOGRAPHY

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13. ABSTRACT *(Maximum 200 words)*

The production of halons for use as total-flood firefighting agents ended in December 1993, and a search has been undertaken to develop alternatives. One of these alternatives involves fine particulate or droplet aerosols. A library search has been accomplished by the New Mexico Engineering Research Institute and the University of Florida to identify references to aerosol usage as replacements for Halon 1301 in total-flood firefighting applications. Two main areas were identified--water mists and pyrotechnically generated aerosols. The references identified were included in the Microsoft™ Access™ USAF/CGET AEROSOL REFERENCE Database, which provides a reference citation, keyword, abstract, and pages for concept development and conclusions as to the potential use of a compound, for each reference. An overview of the technology based on this review was also prepared. This document provides this overview and describes the computerized database and provides a listing of all documents contained in the database.

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ABBREVIATIONS AND ACRONYMS

ADT	Access Developer's Kit
CGET	Center for Global Environmental Technologies
FC (PFC)	perfluorocarbon
HBFC	hydrobromofluorocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
NMERI	New Mexico Engineering Research Institute
PGA	pyrotechnically generated aerosol
RDB	relational database
SQL	standard query language
UF	University of Florida

PREFACE

This report was prepared by the Center for Global Environmental Technologies (CGET), New Mexico Engineering Research Institute (NMERI), The University of New Mexico, Albuquerque, New Mexico, for the Infrastructure Technology Section of Wright Laboratories (WL/FIVCF), Tyndall Air Force Base, Florida, under Contract F08635-93-C-0073, NMERI Number 8-31880. This document provides an aerosol technology overview and a list of references relating to aerosol usage in total-flood firefighting applications.

The Start Date for the project was 22 September 1993, and the End Date was 22 March 1995. The WL/FIVCF Project Officer was Charles J. Kibert and the NMERI Principal Investigator was Robert E. Tapscott.

This document contains only bibliographic citations for the references in the USAF/CGET AEROSOL REFERENCE Database. Most references are complete. Several, however, are only partial and are included for information. Readers with additional information are asked to contact CGET at NMERI.

The AEROSOL Database contains abstracts and comments on potential uses of these aerosols in firefighting applications. The database is available in a format suitable for viewing to users with computers operating in a Windows environment. Contact CGET at NMERI to request a copy.

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EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of the overall "Evaluation of Replacements for Halon 1301 in Total Flood Applications" program is to develop new firefighting agents to replace Halon 1301 in total-flood firefighting applications. The portion of the work described in this document has, as an objective, a library search for documents referring to aerosol usage as a total-flood firefighting agent, the development of a database to contain those references, and the preparation of a technology overview based on the references in the database.

B. BACKGROUND

The production of halons, used for fire and explosion protection, ended on 31 December 1993 in developed nations. Among the candidates proposed to replace halons are aerosol agents. Two aerosol agent types have been identified as having potential to replace Halon 1301 in total-flood fire protection applications—water mists and pyrotechnically generated aerosols (PGA). While water has been used extensively to extinguish fires, it has rarely been considered in a total-flood application due to the large droplet size generated by conventional sprinkler techniques. The large droplet size prevents flow around obstructions and the long suspension times required to extinguish a fire of prevent an explosion. Moreover, the large amounts of water may damage electronics and other objects in the protected space. It has been proposed that fine water mists could provide total-flood protection similar to that provided by gaseous agents such Halon 1301. Dry chemicals have also been used extensively to fight fires, but large particle sizes have precluded their use as total-flood agents. Researchers have produced fine particulates by burning a suitable matrix, thus generating micron-range particles that may provide total-flood protection in some scenarios. The United States Air Force is interested in performing research to determine the feasibility of replacing Halon 1301 with one or both of these aerosols.

C. SCOPE

To ensure that a thorough review of aerosol technology is made, a comprehensive bibliography of all aerosol references must be available. References found in many different journals, books, conference proceedings patent applications, and other sources were found through extensive library searches, and a convenient method of storage and retrieval was developed. An overview of the technology based on the review was written.

D. RESULTS

NMERI and the University of Florida (UF) jointly conducted the library search for references to aerosols. A computerized database, the USAF/CGET AEROSOL REEFERENCE Database, hereafter called the AEROSOL Database, was developed to store the references. This database includes a table of the references and a form that displays a complete bibliographic citation, keywords, and an abstract for each reference, as well as a page each for conclusions on the content of the reference and proposed concepts for firefighting. The AEROSOL Database is linked to the CGET/APT LIBRARY Database, which contains nearly 4000 references on ozone-depleting substance (ODS) replacement, firefighting chemicals and techniques, and related subjects. Only those references in the LIBRARY Database concerning aerosols are included in the AEROSOL Database, which can be distributed to users regardless of whether Microsoft Access. The AEROSOL Database can be searched for keywords or words in the text. The overview presents basic aerosol technology and applications for both water mist and particulate aerosols.

E. CONCLUSIONS

A total of 230 references have been included in the present version of the AEROSOL Database, which is designed to facilitate the addition of new references and searches of current references by topic.

F. RECOMMENDATIONS

It is recommended that the AEROSOL Database be updated as new aerosol references are found to permit researchers in the field to have timely access to references on aerosol technology.

SECTION I
INTRODUCTION

Halon production in the developed world ceased at the end of December 1993. A number of candidate replacement agents have been announced by industry for commercialization, and additional chemicals are under consideration. Most of the announced agents are "first-generation" agents—hydrochlorofluorocarbons (HCFC), hydrofluorocarbons (HFC), perfluorocarbons (PFC or FC), and hydrobromofluorocarbons (HBFC). All of these first-generation candidates, however, have one or more drawbacks in terms of effectiveness, global environmental impact, or regulatory acceptance. Consequently, the search for candidates that are effective but have minimal global environmental impacts has continued.

Aerosol agents are one class of agent identified as potentially effective and with minimal global impact. The size of the particles in these agents is extremely small, in the range of 1 to 50 μm, which may allow the particle to remain suspended in the air for finite periods and could provide total-flood protection similar to that provided by gaseous agents, such as Halon 1301. Two technologies based on particulates have been identified—water mist and particulate aerosols, which are similar to dry agent chemicals but in smaller particle sizes. The particulate aerosols are most commonly pyrotechnically generated aerosols (PGA); however, particulate aerosols generated by non-pyrotechnic methods are being researched. Both water and dry chemicals have been used extensively in the past for firefighting applications, but the large droplet or particle sizes have prevented their use in total-flood applications, where the ability to flow around obstacles and to remain suspended in the air for extended periods is critical. Many researchers believe that the small particle sizes generated in water mists and PGAs (or other small particle techniques) may permit their use as total-flood agents.

As part of the project to investigate the potential of aerosols to replace Halon 1301 in total-flood applications, the New Mexico Engineering Research Institute and the University of Florida conducted a literature search for references on aerosols, developed a database for storage and retrieval, and prepared an overview of the technology based on the literature search. Section II gives the overview of technology; Section III presents information on the database; Section IV explains the format of the data in the database; and Section V provides recommendations.

SECTION II
AEROSOL TECHNOLOGY OVERVIEW

A. BACKGROUND

Halons have been used for many years to fight fires. However, a 1974 article by M. J. Molina and F. S. Rowland identified halogenated compounds such as halons and chlorofluorocarbons (CFC) as potentially depleting the earth's ozone layer (Reference 1). In 1978, the United States banned the use of CFCs in nonessential aerosol products. Despite this action, the global production of CFCs and halons continued and regulatory actions occurred. The Montreal Protocol, an international treaty signed in 1987, placed a cap on the consumption of halons. Effective 1 January 1994, halon consumption (production plus imports minus exports) was phased out in the United States and other developed nations.

A concentrated effort to develop substitutes for halons has been undertaken over the past few years. Halon substitutes can be divided into two types: replacements and alternatives. Replacements are halon-like agents, e.g., halocarbons. Alternatives are non-halon-like materials sometimes called "not-in-kind" agents (e.g., dry chemicals, inert gases, foam, water, carbon dioxide). Nearly all work on halon replacements has focused on halocarbons. Owing to increased concerns about global warming, atmospheric lifetime, and ozone depletion, however, halocarbons are becoming less acceptable as halon replacements, and alternatives are receiving increased attention. Recently, two alternative technologies—water misting and low-residue particulates—have come to the attention of researchers. These technologies may allow the use of water or dry chemical in reduced quantities to provide acceptable fire protection. Since the amount of agent required is reduced, secondary fire damage due to agent residue may also be significantly reduced.

B. INTRODUCTION

The search for replacements and alternatives for the halon family of chemical fire suppressants has coincided with the development of novel materials and techniques that provide new options for fire protection. One class of materials that has good potential for filling several roles formerly performed by halons is solid particulate fire suppression aerosols. Originating as solid materials, micron-size solid aerosol particles are generated via combustion of a solid material consisting of a combination of oxidizer, reducer, and binder. Researchers are pursuing the development of solid particulate aerosol fire suppressants for their potential both as an alternate to Halon 1301 fire protection systems and as a fire protection method of choice for certain applications. Researchers are also investigating a wide range of liquid aerosols, such as water and halocarbon mists, both of which have demonstrated significant fire suppression effectiveness for relatively small quantities of originating material.

Aerosol science or particle mechanics draws from several scientific disciplines to formulate the science that underlies its principal areas of research. Understanding the thermodynamic interaction of aerosols with fire propagation mechanisms is a new subset of aerosol science that has the potential for creating a wide variety of fire suppression options.

C. AEROSOL CONCEPTS

Aerosol refers to a system of liquid or solid particles suspended in a gaseous medium. Aerosols are generally defined as stable or quasi-stable systems with the bulk of particles being $< 1\ \mu m$ in diameter. Note, however, that water mists are often designated as aerosols, and such mists are usually made up of water droplets with diameters of 50 μm or more. Aerosols affect visibility, causing some degree of obscuration, especially in the size range of 0.1 to 1 μm. The collective term "particulate" is commonly used to refer to both solid and liquid (particle and droplet) components of an aerosol when differentiation of phases is unimportant. Here, however, the term "particulate" is used to refer to solid aerosols. Several common aerosols are fumes, smoke, mists, fog, and haze.

Fumes resulting from chemical reactions may become aerosols via agglomeration of molecules due to high Brownian diffusion rates. Particle sizes vary greatly as a function of temperature and gas volume. Once formed, separation and rediffusion become very difficult.

Metal fumes have particle sizes on the order of 0.5 μm. Smoke is an aerosol resulting from combustion of fuels. Like fumes, smoke has particle sizes on the order of 0.5 μm.

A solid aerosol particle can have a wide variety of shapes, but is often considered to be virtually spherical for analysis purposes. The radius, r, or the diameter, d_p, can therefore have several definitions. Because most studies utilize the projected image of the particles, the dimension of the particle is related to the analysis technique. The Feret diameter is the maximum edge-to-edge distance of the particle, while the Martin particle diameter is the length of a line that separates the particle into two portions of equal area. The aerodynamic diameter, d_{ae}, is the diameter of the spherical particle of unit density that would exhibit the same aerodynamic properties as the aerosol particle. The Stokes' diameter, d_{St}, is the diameter of a sphere that would have the same density as the aerosol particle (Reference 2).

Based on the state of the suspended substance, liquid or solid, dispersion and condensation aerosols are differentiated. Dispersion aerosols are formed by the atomization of solids and liquids, while condensation aerosols are formed via the condensation of superheated vapors or chemical reactions in the gaseous phase. In general, dispersion aerosols are coarser than condensation aerosols.

D. AEROSOL DYNAMICS

The dynamics of aerosols is an important consideration for two reasons. First, the ability of the particles to remain suspended is obviously connected to the particle size and the residence time of the fire suppressant. Second, if aerosols are to replace gases in certain applications, they must be able to flow around obstacles.

The suspension time of an aerosol is governed by Stokes' Law, which predicts the terminal velocity of the particle through air and consequently the residence time of the aerosol. As particle size increases, the inertial and viscous forces of the fluid come into play. For larger particle sizes, the Stokes' Law predictions must be recalibrated for viscous drag forces.

The ability of the fire suppressant aerosol to flow around obstacles is required for it to be able to penetrate around and behind objects and into small spaces. The larger the particle size, the less able the particle will be to change direction, causing it to impinge on the obstacle. This property is called impaction and is governed by Stokes' number or the impaction parameter, which is the dimensionless ratio of the particle stopping distance to the characteristic dimension of the obstacle or flow geometry (Reference 3).

Dispersion of an aerosol fire suppressant is an important consideration in evaluating effectiveness. The dispersion characteristics of the aerosol are also a function of the aerosol particle size. In general aerosol particles vary widely in size, from 1 nm to about 1 mm as the upper limit. Coarse particles with $r > 1\ \mu m$ have a dispersion rate that is a function of diameter. Particles in the range, $0.1\ \mu m < r < 1.0\ \mu m$, have transition properties. Very fine particle aerosols with $r < 0.1\ \mu m$ are dispersed proportional to r^2 and the particle velocity, v.

The loss of aerosol particles in suspension can be attributed to several phenomena: sedimentation, diffusion, and coagulation. Again, the size and velocity of the aerosol particles are the driving force. Larger particles, $r \geq 1\ \mu m$, will tend to fall and be lost via sedimentation. Smaller, submicron particles, will tend to diffuse out to the walls of containment via Brownian motion. Coagulation, the formation of larger particles from smaller particle via collisions, is caused by thermal, electrical, molecular, hydrodynamic, and several other forces.

E. FIRE SUPPRESSION AEROSOLS

A solid particulate fire suppression aerosol is a dispersion aerosol that is delivered to the protected space. Recently, aerosols have been generated by combustion of a solid tablet. Prior to the development of the particulate aerosols, dispersion aerosols were created via crushing, grinding, blasting, or drilling of solid matter. The particle size reduction is directly related to the energy expended on crushing or grinding and other factors such as the brittle or plastic nature of the material, the porosity of the solid, and the presence of crystal flaws and sites of weakness. Physico-chemical reactions using condensation processes have also been used to generate solid particulate aerosols. Salts fused on heating wires have been used to generate aerosols via incandescence in inert gas atmospheres, the temperature being a function of the energy required to produce nuclei.

Solid particulate fire suppression aerosol particles are on the order of 1-3 μm in diameter. At 1 atmosphere, these particles will have a terminal velocity of about 10^{-4} cm/s according to Stokes' Law. Diffusion losses are also predicted to be very small. The result is that these particles will remain suspended in the protected space for times on the order of tens of minutes to several hours.

Pyrotechnically generated solid particulate fire suppression aerosols are initially a solid material that can originate in a variety of forms: solid, powder, or gel. The active components (an oxidizer and a reducer) are combined with a filler. These components are ground into a fine powder and mixed with an epoxy resin binder. Upon ignition of the material, the combustion products are ejected as a dispersion aerosol, with the solid particles floating in the air with the gaseous components.

The products of combustion of most fire suppression PGAs are 40 percent solid particles and 60 percent gaseous products. The gaseous products consist of N_2, CO_2, CO, H_2O, O_2 and traces of hydrocarbons. The solid particles are various solid salts, depending on the formulation of the originating solid.

F. EXTINGUISHMENT MECHANISMS

Successful fire suppression requires that one or more of the four factors that tend to propagate a fire be interrupted. These factors and their associated suppression mechanisms are shown with the action of the aerosol as a fire suppressant (Table 1). Solid particulate aerosols, like dry chemicals, are hypothesized to function via several mechanisms to suppress fires.

TABLE 1. FACTORS GOVERNING FIRE PROPAGATION.

Factor	Suppression Mechanism	Aerosol Actions
Fuel	Removal	N/A
Oxygen	Exclusion	Inert gas formation
Heat	Absorption	Cooling via decomposition/vaporization
Chain reaction	Inhibition	Absorb active species

Chemical inhibition of the chain reaction is hypothesized to occur via catalytic combination of the active free-radical species. There is also significant evidence that heat absorption and cooling via decomposition and vaporization of the solid particles is an important mechanism for flame extinguishment. The final mechanism may be oxygen dilution in the flame region as the chemical reaction of the particles and active species produces inert gases such as CO_2, causing localized low oxygen conditions.

1. Chemical Inhibition Interactions

Chemical inhibition is a function of several variables. Depending on the temperature at the point of interaction, the aerosol particles can act by homogeneous inhibition, as shown in the following examples for a potassium-containing agent:

$$K + OH + M \text{ -----> } KOH + M \quad (1)$$

$$KOH + H \text{ -----> } H_20 + K \quad (2)$$

$$KOH + OH \text{ -----> } H_20 + KO \quad (3)$$

where M is third-body molecule (e.g., nitrogen or argon), and H and OH are active species. The extinguishing process is in fact similar to that of the halons.

Chemical precursors that interact with the active species are often the alkali metals K, Na, Cs, Rb, Sr and associated anions such as CO_3, HCO_3, SO_4, NH_4, and PO_4. The alkali-metal salts have been shown to be especially effective fire suppressants. The potassium salts are generally superior to the sodium salts and the anion associated with each is an important factor in fire suppression effectiveness (Reference 4). For example, alkali metal oxalates are particularly effective compared to bicarbonates.

Fragmentation of dry chemical agents, such as alkali metal salts, increases the particulate-specific area for interaction. Large dry chemical particles may decompose in flames to produce inhibiting species, such as alkali hydroxides. To allow decomposition to occur, residence time in the flame is important. For large particles, the appropriate residence time may be difficult to achieve because the mass of the particle will cause it to fall rapidly through the flame. In the case of 1 μm aerosol particles, the residence time required to produce the reactive species is far shorter and the diffusion property of the small solid particle will tend to maintain its availability in the flame. The combination of these effects may result in the increased effectiveness of particulate aerosols compared to dry chemical fire extinguishants of similar composition. Clearly, the penetration of the flame by these particles is a complex phenomenon and must include considerations of density, momentum, and the convection characteristics of the scenario in addition to the particle size. The large particle sizes of dry chemicals may have some advantage in flame penetration compared to the small aerosol particles because of their momentum.

2. Thermal Cooling Mechanisms

Relatively recent evidence suggests that much of the effectiveness of dry chemicals can be attributed to thermal and heat extraction mechanisms such as heat capacity, fusion, vaporization, and decomposition (Reference 5). At certain particle sizes, depending on the dry chemical powder composition, a sizable increase in extinguishing effectiveness is achieved that can be explained by flame heat removal (References 6 and 7). This occurs at limit temperatures that are a function of the flame and extinguishant properties. The particle size at which the step increase in effectiveness occurs is the limit size, S_L, defined as the largest particle size that completely reacts with the flame. The S_L varies with the composition of the dry chemical constituent of the formulation. Above S_L, heat extraction is due to the heat capacity of the solid particle alone. Below S_L, several mechanisms are effective including heat capacity, dissociation, decomposition, and vaporization. Plots for five dry chemicals—$KHCO_3$, Monnex,

$NH_4H_2PO_4$, $NaHCO_3$, and KCl—are contained in Reference 6. These graphs provide valuable insights into the behavior of dry chemicals as a function of particle diameter as well as impetus to examine dry chemical aerosols that appear to be especially effective.

In addition to the differences in relative effectiveness of various dry chemical formulations, for the same alkali metal the fire suppression efficiency as a function of the anion appears to be as follows:

Oxide > cyanate > carbonate > iodide > bromide > chloride > sulfate > phosphate

The generation of alkali hydroxide in the flame is believed to be the reason for the relative effectiveness of the various anions.

G. APPLICATIONS

1. Pyrotechnically Generated Aerosols

The aerosol generated when an PGA tablet is ignited has several properties that differentiate it from both gaseous agents and dry chemicals. In fact, PGA could be said to be an intermediate agent between these two extremes in fire suppression techniques. The following are several of the key characteristics and features of PGA that influence the design of applications:

a. Similar to (but less effectively than) a gaseous agent, PGA can flow around barriers and obstacles, behaving like a gas in its basic transport properties. It can be introduced into ductwork and be delivered to an area via forced convection. Dry chemicals, in contrast, are more limited by obstructions.

b. PGA has excellent Class B fire suppression characteristics, similar to those of dry chemicals. Both PGAs and dry chemical agents are about 4 times as effective as Halon 1301 per unit mass and up to 10 times as effective as the proposed first-generation replacements for Halon 1301.

c. PGA initiation is independent of oxygen supply and can, therefore, be effective under or within a liquid or at altitudes where oxygen concentrations are low.

d. Initiation of PGA can be active via electrical ignition or passive via self-ignition due to interaction with a fire.

e. The delivery rate of PGA is a function of its composition, form (solid, powder, gel), and the delivery system. The aerosol is generated by combustion of the PGA material; variations in the active component, oxidizer, and reducer dramatically affect the burn rate, perhaps up to a difference of two orders of magnitude.

f. PGA does not require piping, pressure cylinders, or valves. A device for containing the PGA solid material is all that is normally required. Pressure testing, weighing, pressure/leak detection, and other maintenance and testing of cylinders/pipes/nozzles/valves are not required.

The low weight to extinguishment capability of PGA provides tremendous performance advantages for weight- and space-critical applications. A CO_2 cylinder weighing more than 150 Kg could be replaced with about 4 Kg of PGA.

It has been demonstrated that small particle dry chemicals (below S_L in size) can be created by mechanical means. However, practical utilization of mechanically created, small diameter dry chemical compounds is limited because it is difficult to store dry chemicals for extended periods of time without compaction. Humidity also has a detrimental effect on dry chemicals and results in deterioration. The production of dry chemical solid particulate aerosols by combustion avoids these difficulties, and the solid material has an estimated 15-year shelf life. Packaging can be readily designed that provides protection even in fairly extreme environments.

This excellent performance capability and its add-on ability will enable PGA use in applications such as trucks and cars, boats and ships, engine compartment protection, fuel tanks, and numerous other applications. Where portability, expandability, simplicity, ruggedness, and cost are factors, a solid particulate aerosol system should be considered.

The major unknowns for PGAs at present are materials compatibility, especially corrosion, and application against deep-seated fires. Testing to assess aerosol performance in both of these areas is ongoing.

2. Water Misting Systems

Water misting systems allow the use of fine water sprays to provide fire protection with reduced water requirements and reduced secondary damage. Calculations indicate that on a weight basis, water could provide fire extinguishment capabilities better than those of halons provided that complete or near-complete evaporation of water is achieved. Since small droplets evaporate significantly faster than large droplets, the small droplets achievable through misting systems could provide this capability. No criteria have yet been established on the dividing line between mists and sprays; however, droplet sizes of 100 μm or less are often used as a criterion.

Work on misting systems in the U.S. has been scattered. A thorough review has been written by the Navy Technology Center for Safety and Survivability and Hughes Associates (Reference 8). Concepts and some studies were described at the Water Mist Fire Suppression Workshop, at the National Institute of Standards and Technology (1-2 March 1993). Work has been performed by the Fire Research Station in England on non-total-flood applications, primarily aircraft crash/rescue, the Channel Tunnel, and streaming. Water misting has been found to be effective in suppressing flammable liquid fires (Reference 9), and it has been considered for use in spacecraft (Reference 10). The Naval Research Laboratory is examining water misting nozzles to simulate Halon 1211 for firefighter training. A recently completed program evaluated water mists for residential applications (Reference 11). At the request of EPA, the Halon Alternatives Research Corporation has convened a peer review panel of the potential health effects of water mist.

There are two basic types of water mist suppression systems: single-fluid (high-, medium-, and low-pressure) and dual-fluid systems. One of the more common types of single-fluid systems utilize water stored at high pressure (40-200 bar) and spray nozzles that deliver drop sizes in the 10 to 100 μm diameter range. Dual systems use air, nitrogen, or other gas to atomize water at a nozzle. Both types of systems have been shown to be promising for fire suppression. It is more difficult to develop single-phase systems with the proper drop size distribution, spray geometry, and momentum characteristics. Dual-fluid systems have a higher spray energy for a given water pressure, are a comparatively low pressure system with a maximum air and water pressure in the lines of about 100 psi (some single-fluid systems require pressures of 1000 to 3000 psi depending on the nozzle design), and have larger nozzle orifices, which may have greater tolerance to dirt and contaminants and thus allow the use of higher viscosity antifreeze mixtures. Single-fluid systems require only storage of water, whereas dual-fluid systems require storage of both water and atomizer gas.

The performance of a water mist system depends on two factors: (1) the ability to generate small droplet sizes and (2) the ability to distribute mist throughout a compartment in concentrations that are effective (Reference 8). Five characteristics are important in determining success or failure of a misting system to protect an area: (1) droplet size, (2) droplet velocity, (3) spray pattern, (4) momentum and mixing characteristics of the spray, and (5) geometry and other characteristics of the protected area. At this time, the effect of these factors on system effectiveness is not well known.

Water mist systems are reasonably weight efficient. The use of small diameter distribution tubing and the possible use of composite, lightweight, high-pressure storage cylinders would increase this efficiency. It may also be possible to integrate a "central storage" of agent for use in several potential fire locations (for example, aircraft cargo and passenger cabin locations). This would further increase the benefit.

The major difficulties with water mist systems are those associated with design and engineering. These problems arise from the need to generate, distribute, and maintain an adequate concentration of the proper size drops throughout a compartment while gravity and agent deposition loss on surfaces deplete the concentration. Water mist systems have problems extinguishing fires located high in a space away from the discharge nozzles. Water mists also have difficulty extinguishing deep-seated Class A fires. Other concerns that need to be addressed are (1) collateral damage due to water deposition; (2) electrical conductivity of the deposition; (3) inhalation of products of combustion due to lowering and cooling of the smoke layer and adhesion of the smoke particles to the water drops; (4) egress concerns due to loss of visibility during system activation; (5) lack of third-party approvals for most or all applications; and (6) lack of design standards (Reference 12).

3. Conclusions

The development of aerosol fire suppression systems is a newly emerging discipline that holds great promise in offering an excellent option for consideration for several fire protection roles. An ongoing Air Force research program is examining the basic physics and chemistry of fire suppression aerosols and assessing the employment of aerosol delivery systems for a variety of applications.

SECTION III
DATA SEARCH

A literature search has been performed, surveying research conducted in the field of aerosol fire suppressants and other fields closely allied to the development of aerosol fire suppressants. The results of this survey are an annotated bibliography of sources in the AEROSOL Database. The titles of the references are presented in the Appendix.

The literature survey is comprehensive and includes domestic and foreign documents produced over the past 20 years that directly or indirectly affect the outcome of ongoing and future aerosol fire suppression research, including Soviet and Russian literature on this subject. The following resources were searched: (a) books, (b) journals, (c) trade publications, (d) periodicals, (e) newsletters, (f) technical reports, and (g) proceedings of conferences.

Copies of most of the documents found during the search are located in the NMERI APT Library. While every attempt was made to obtain all documents and include complete bibliographic citations in the database, several documents, especially foreign patents, were unavailable and complete citations were not included. It was decided that these incomplete references are nonetheless valuable, and efforts will continue to obtain the complete citation, if not the document itself.

SECTION IV
AEROSOL DATABASE

A large amount of data on aerosols and their use in firefighting applications is available in periodicals, reference books, and manufacturers' information. However, up to this time, no single source exists that contains all these references. To provide an accurate, convenient source of aerosol references, a computerized relational database (RDB) was designed to manage the storage, addition, and update of data.

The USAF/CGET AEROSOL REFERENCE Database (hereinafter called the AEROSOL Database) contains a listing of references on the use of aerosols in firefighting applications. The source documents from which data are extracted are referenced to sources contained in the CGET/APT LIBRARY Database© (herein called the LIBRARY Database). Most changes to the AEROSOL Database must be made in the LIBRARY Database. The AEROSOL Database is a relational database (RDB), written in Microsoft Access using a Windows environment (Reference 13). The entire database, with an executable program, has been made available for distribution using the Access Developer's Toolkit (ADT) for Windows.

RDBs are sophisticated filing and cross referencing systems. Among the several advantages of RDBs are those listed below (Reference 14).

(1) RDBs allow relations to be established between tables of data to eliminate problems with multiple changes and duplication. It is important that data changes not be required in more than one location. For example, each individual piece of information appears in only one place. Thus, a single change for a value applies to all locations of that data in forms, queries, etc.

(2) RDBs allow informational exchange with other applications. For example, with appropriate software, the AEROSOL Database can "launch" data to word processing applications for compiling reports or inclusion in other documentation. In general, controls on the database are labeled "launch" for creation of a Word for Windows merge file, and "print" for printing reports directly from Access.

(3) Structured Query Language (SQL) allows searches and compilations of data to be made rapidly and easily.

A. DATABASE STRUCTURE

The AEROSOL Database contains two types of entities: primary objects (Tables, Queries, Forms, Macros, and Modules) and control objects (where data are entered and displayed), which are often part of the former. Here, only primary objects are discussed.

(1) Tables, which contain the data in fields, are the most important part of any database. Tables contain records composed of fields, such as the author or abstract fields, e.g., the primary table (**tblAerosol**) contains one record for each reference.

(2) Queries permit the manipulation, sorting, and retrieval of data. The AEROSOL Database uses two types of queries: "Select" and "Make Table." "Select" queries, which are included both as SQL and standard queries within the database, generate temporary sets of filtered data, whereas "Make Table" queries generate a table of data.

(3) Forms provide a convenient way to view, add, and change data in the tables. Forms are used primarily on the computer screen, although they can be printed out. Each separate datum on a form is contained in a control, which allows data entry or display.

(4) Reports can be used to generate printed information from data in tables or data selected by queries.

(5) Macros permit programming for conducting repetitive functions.

(6) Modules employ computer language to carry out complex functions.

The various objects in an RDB (including control objects) are often named using a special convention (Reference 15), and that convention has been followed here for the primary objects and most, but not all, control objects. Each object is given a name that contains a tag and a Base. In addition, there may also be a prefix (rarely used) and a Qualifier. The names have the following form: [prefix]tagBase[Qualifier]. The prefix (if any) and the tag are lower case. The first letter of both the Base and Qualifier are capitalized. Suggested tags are given in Table 2.

Qualifiers are much less well defined; however, a few suggested qualifiers are shown in Table 3. Qualifiers are not used in the present version of the AEROSOL Database.

B. TABLES

A list of the tables in the AEROSOL Database is shown in Table 4. The AEROSOL Database has two primary tables. The table **tblAerosol** contains a reference number to the LIBRARY Database and comment data. The table **tblTotalQ** contains data on publications and authors attached from the LIBRARY Database. The table **ztblLaunchQ** is generated by queries. (In this and other databases designed by NMERI/CGET, a "Q" is added as a suffix when naming generated tables.) This table is used only to contain final input for "launch" into word processing programs or to reports printed by Access. Note that this table is generated by more than one query and, therefore, the structure may change depending on the query used. This table does not contain permanent data.

TABLE 2. TAGS FOR OBJECT NAMES.

Primary (Container) Objects		Control Objects	
Object	Tag	Object	Tag
Form	frm	Chart	cht
Macro	mcr	Check Box	chk
Module	mod	Combo Box	cbo
Query (Select)	qry	Command Button	cmd
Query (Append)	qrya	Frame	fra
Query (Crosstab)	qryc	Label	lbel
Query (Delete)	qryd	Line	lin
Query (Make Table)	qrym	List Box	lst
Query (Update)	qryu	Option Button	opt
Report	rpt	Option Group	grp
Table	tbl	Page Break	brk
		Shape	shp
		Subform	sfrm
		Text Box	txt
		Toggle Button	tgl

TABLE 3. COMMON QUALIFIERS.

Property	Qualifier
First Element of a Set	First
Last Element of a Set	Last
Next Element of a Set	Next
Previous Element of a Set	Prev
Lower Limit of Range	Min
Upper Limit of Range	Max
Source	Src
Destination	Dest

TABLE 4. TABLES IN AEROSOL DATABASE.

Name	Number of Records*	Description
tblAerosols	230	Ties into LIBRARY Database for citation, abstract, and keyword data, and provides comment and identification field for each record.
tblTotalQ	3942	Table of all references generated from the LIBRARY Database.
tblTotalQQ	230	Table of references contained in AEROSOL Database.
ztblLaunchQ	varies	Temporary table used in launching information to reports and word processing.

* These were the total number of records at the time this report was written; in most cases, the totals will change as the database is expanded.

C. QUERIES

The AEROSOL Database contains qrymLaunch (Table 5), a make query, which allows selection of records for printing in an Access report, or export to Microsoft Word.

TABLE 5. QUERIES IN AEROSOL DATABASE.

Name	Type	Description
qrymLaunch	Make Table	Used for data launch or print

D. FORMS

Forms (Table 6) provide the major interface between users and the AEROSOL Database. Forms whose names have the suffix "mod" are modal pop-up forms, which, in the present database, are used for finding records or for data unit conversions. Figures 1-7 present the forms as seen on the monitor when using the database.

When the database is opened, the **frmSwitchboard** form appears, allowing access to the Aerosol form and permitting the launching and printing of data. A copy of the database suitable for inclusion in the ADT version may be made by pressing the "Make Distribution Copy" button. The form **frmAerosol** is the principal form for the AEROSOL Database. This form allows the viewing of data within those tables, as well as providing capability to find records and select records based on certain criteria. Form **frmAddRecordMod** allows new references from the LIBRARY Database to be entered, while **frmFindMod** allows a search on text terms.

TABLE 6. FORMS IN AEROSOL DATABASE.

Name	Description
frmAddRecordMod	Allows addition of new records from LIBRARY Database
frmAerosol	Principal form for tblAerosol.
frmBackground	Covers screen during time-consuming operations.
frmGlobal	Hidden form for temporary storage of variables.
frmFindMod	Allows search on text terms.
frmSwitchboard	Initial form displayed upon entry.

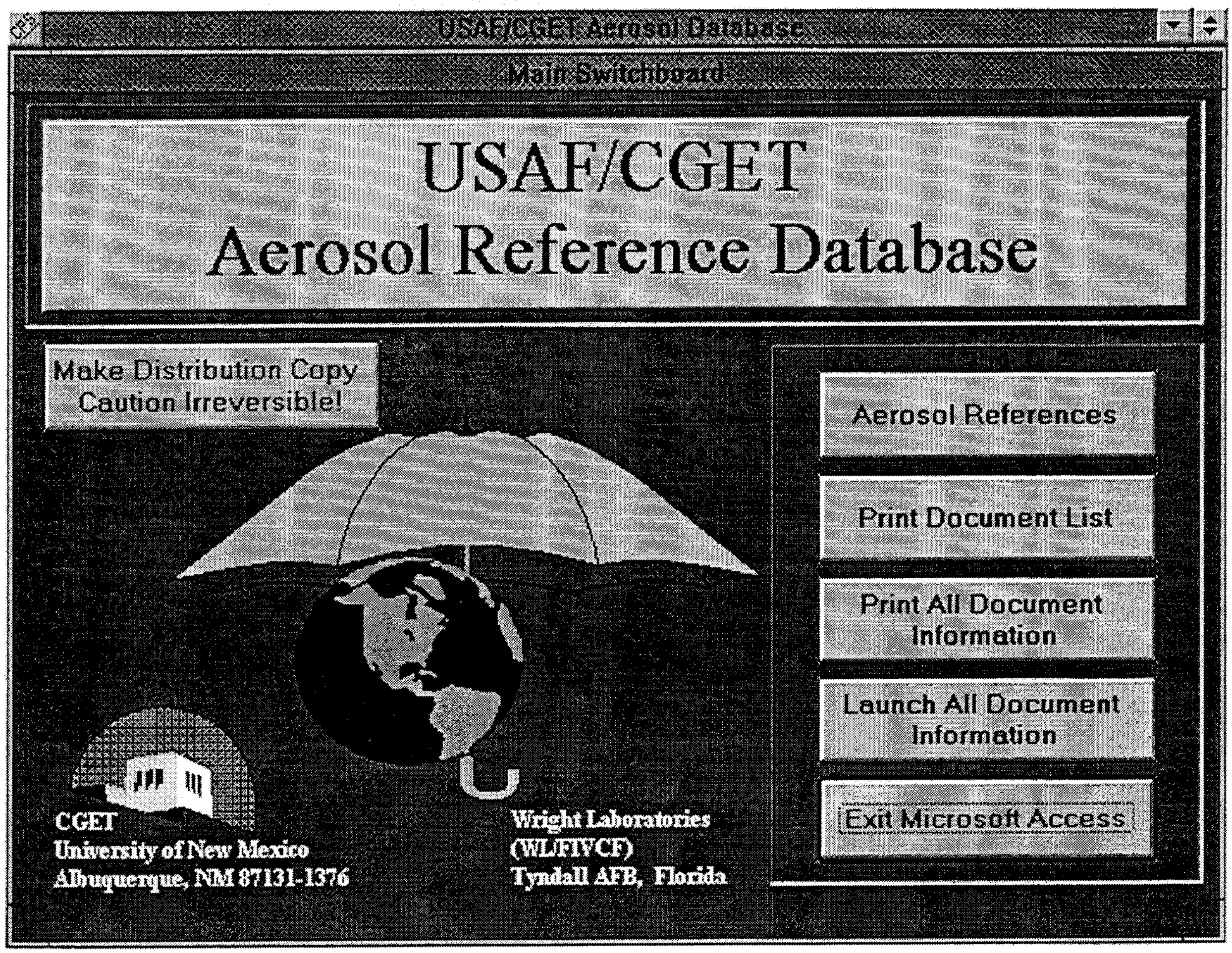

Figure 1. Switchboard Screen.

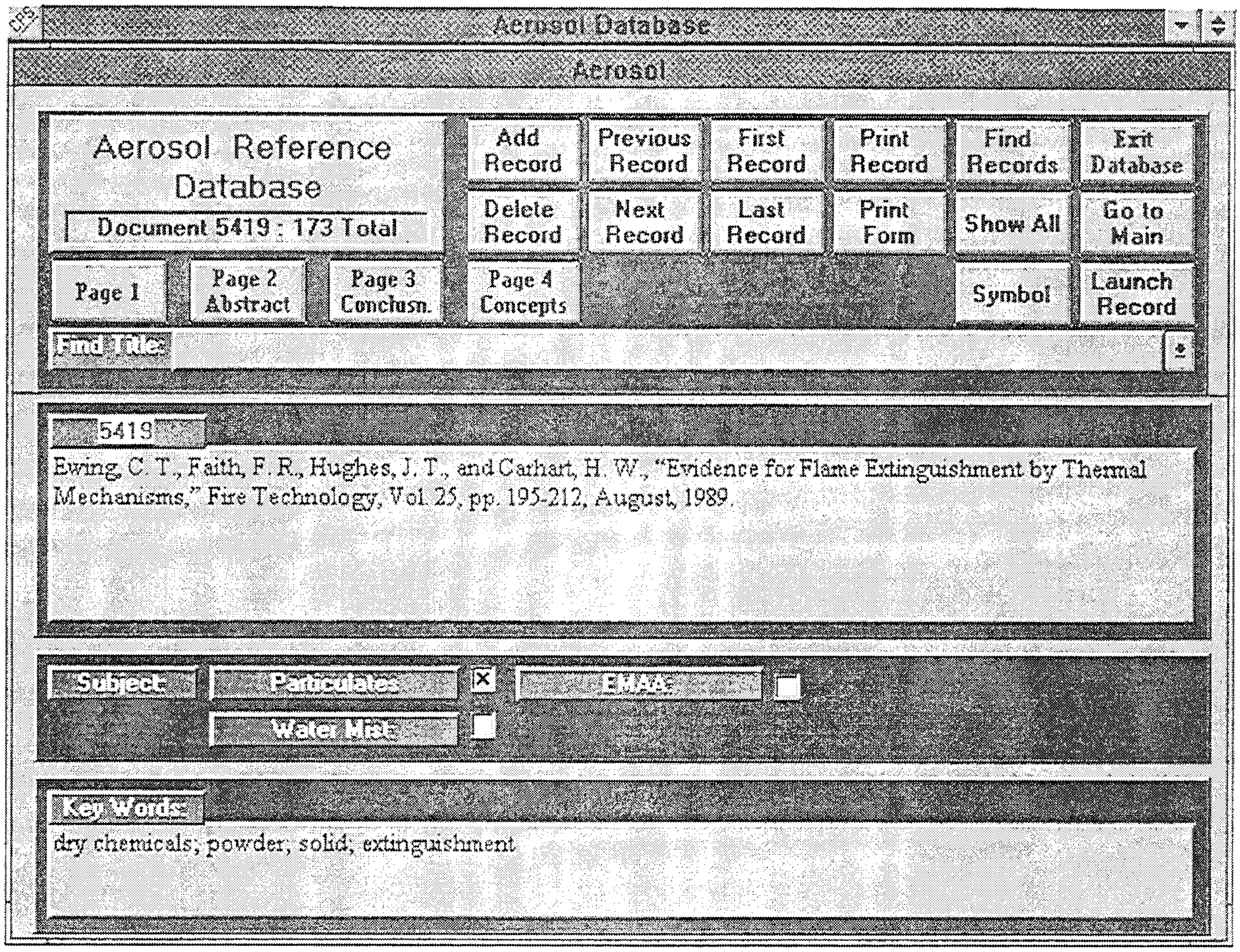

Figure 2. Entry Screen.

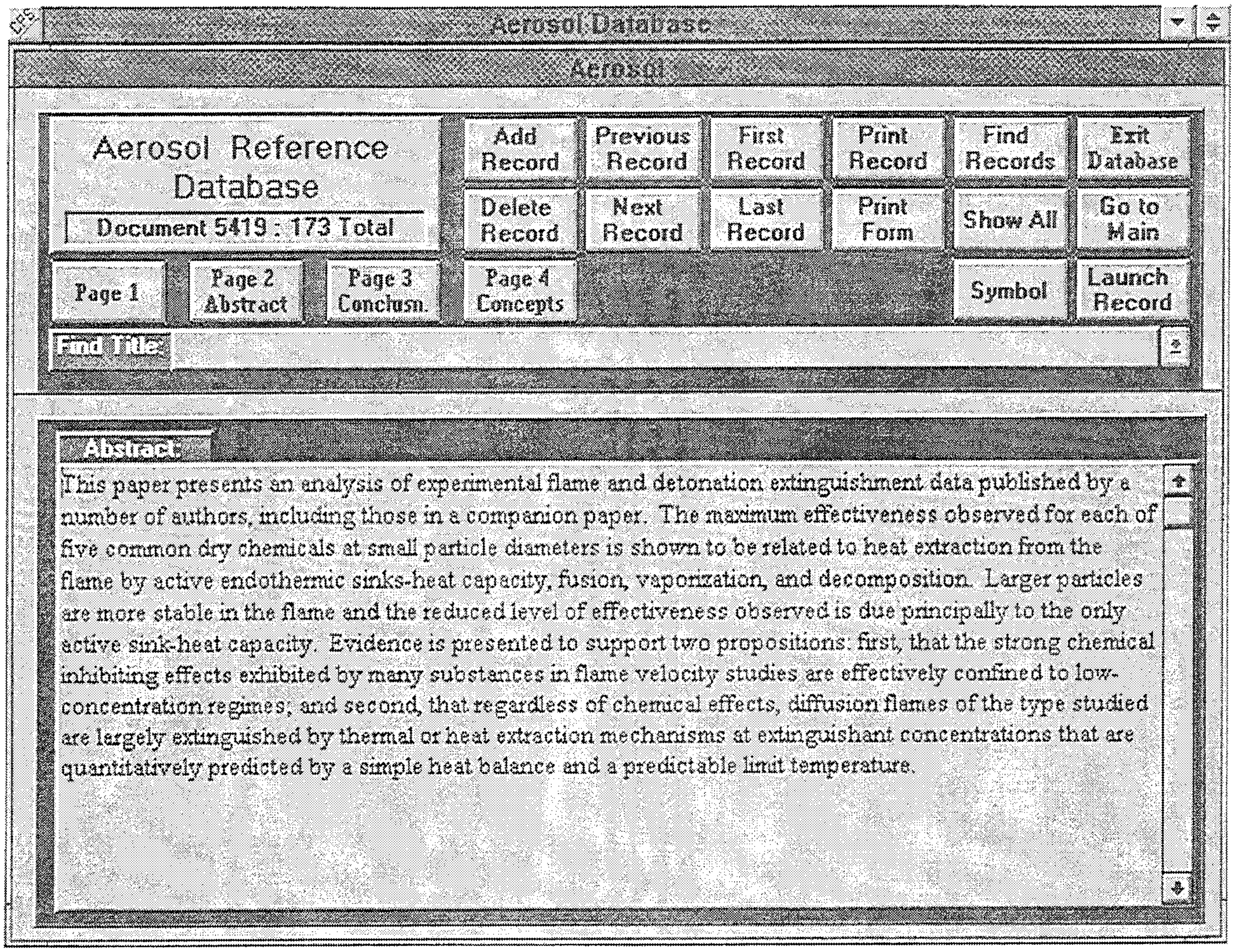

Figure 3. Abstract Screen.

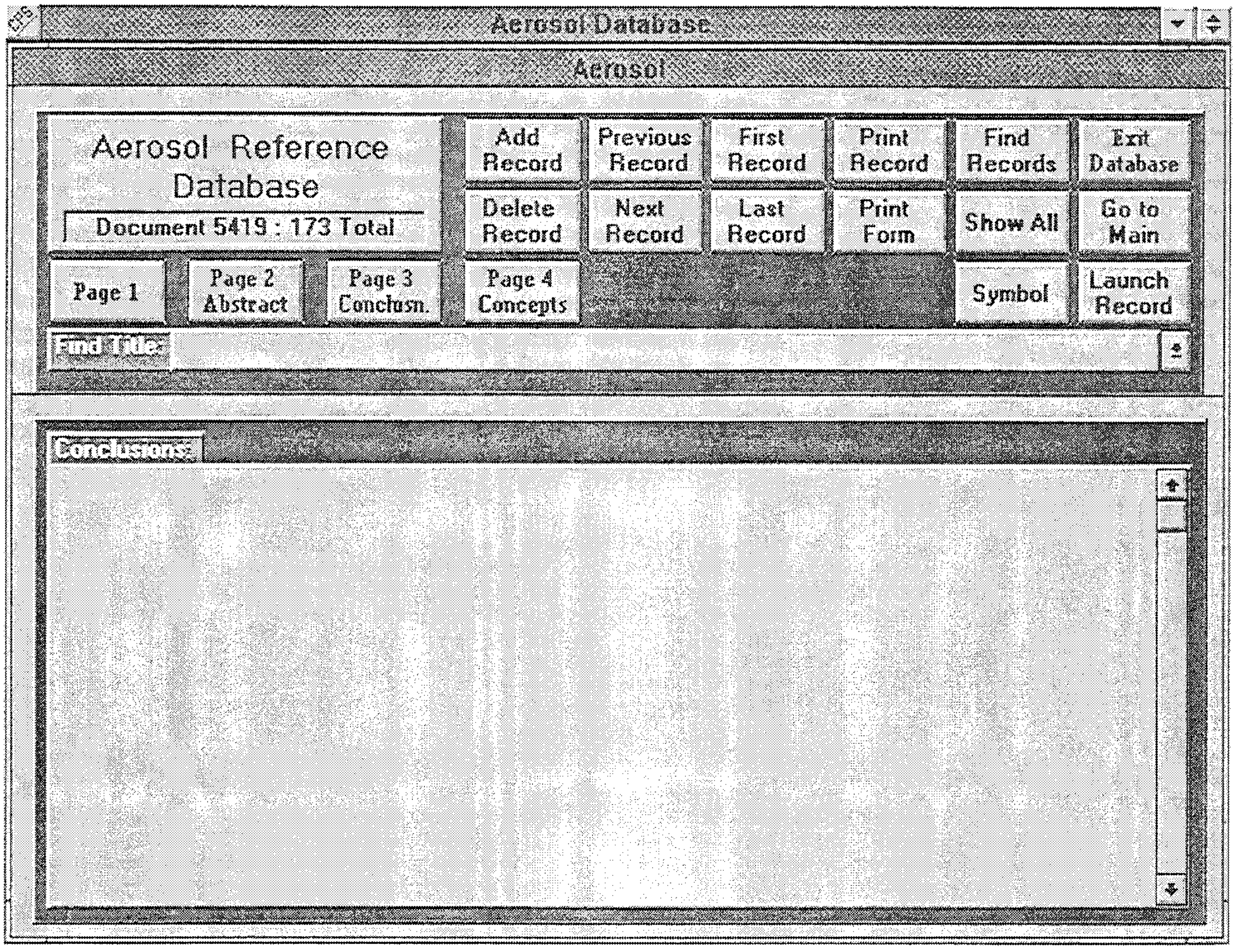

Figure 4. Conclusions Screen.

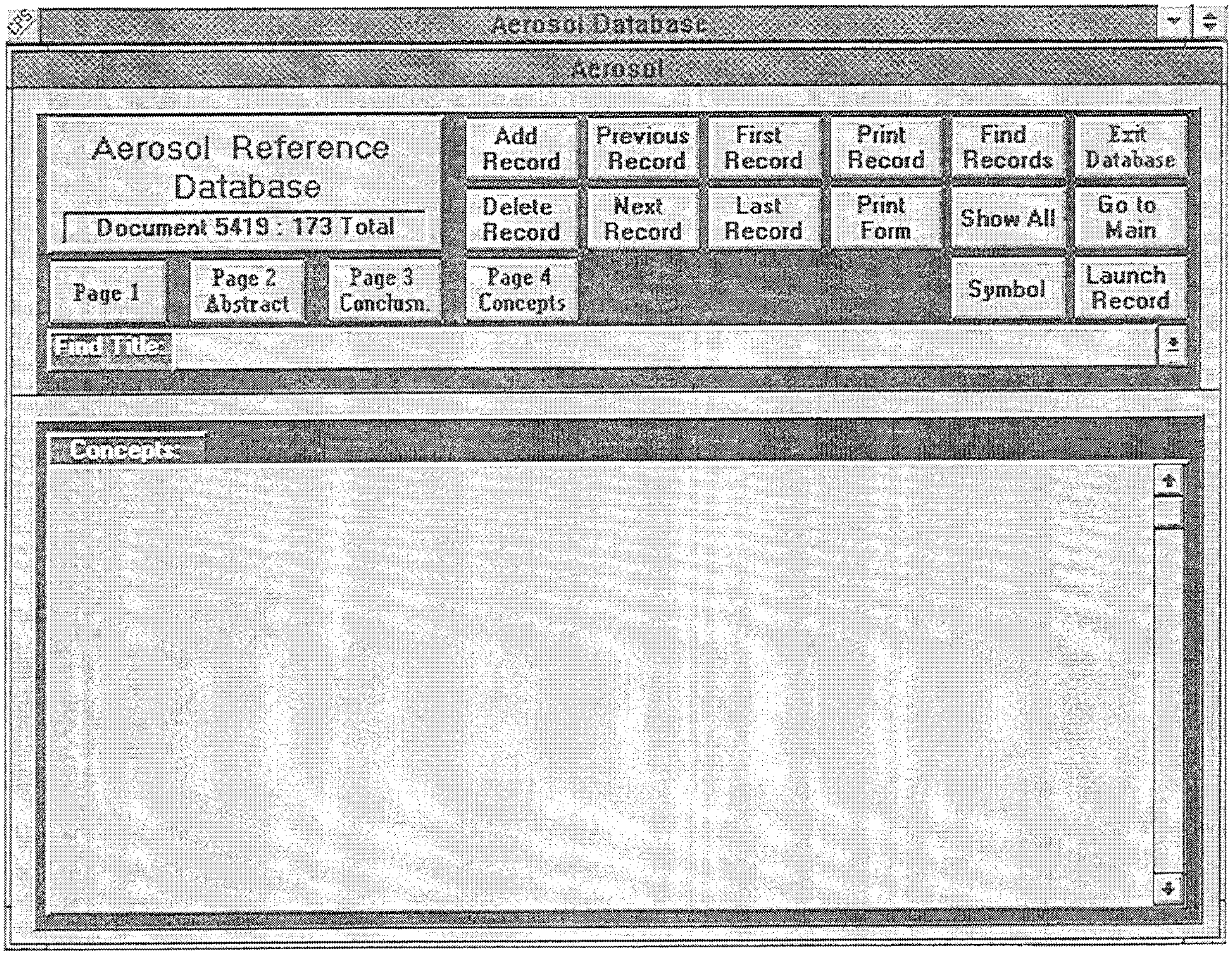

Figure 5. Concepts Screen.

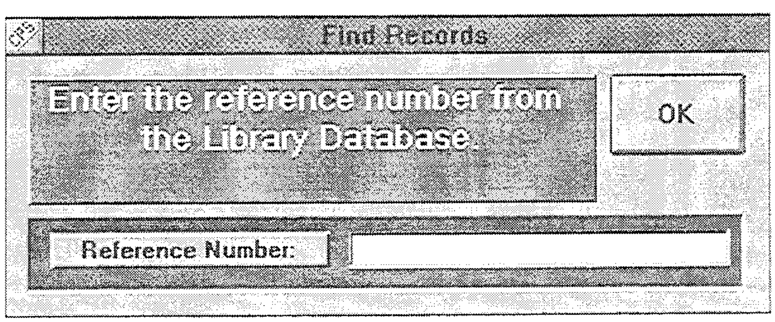

Figure 6. Add Record Screen.

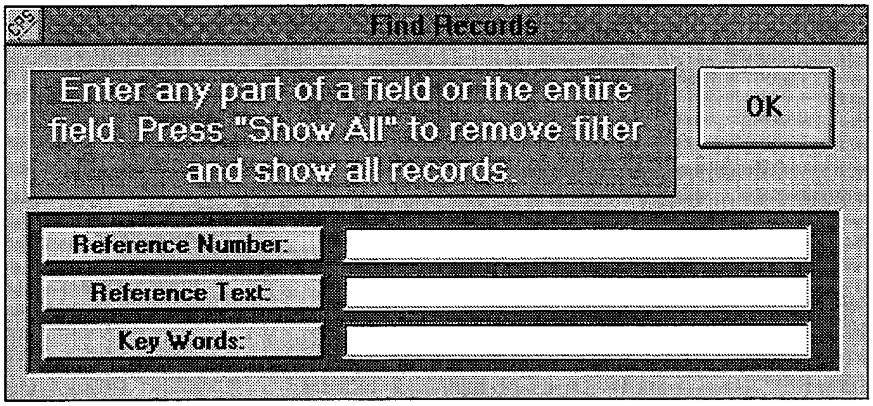

Figure 7. Find Screen.

E. REPORTS

The present AEROSOL Database will produce two printed reports (Table 7): **rptAerosol** allows printing of the records in a summary (citation) and **rptList** allows printing in a more complete (one page per record) format.

TABLE 7. REPORTS IN AEROSOL DATABASE.

Name	Description
rptAerosol	One-page printout of citation, keywords, abstract, conclusions, and comments.
rptList	Listing of LIBRARY Database reference numbers and complete citation.

F. MACROS

The macros used by the AEROSOL Database are listed in Table 8. Note that, with the exception of Autoexec, each of these is actually a set of several macros with related functions.

The **Autoexec** macro sets up the database and brings up the **MainSwitchboard** form when the AEROSOL Database is first started. This macro also hides the database window, changes the window caption, and makes adjustments in the window. The macro **mcrChangeWindow** contains the macros that allow movement from one form to another; **mcrFind** contains all of the macros associated with finding specific records when the "Find Record" buttons are activated on a form; and **mcrForm** is a generalized set of macros used in manipulating forms. The macro **mcrLaunch** contains macros to print data in reports or to launch data to a Word for Windows merge file.

TABLE 8. MACROS IN AEROSOL DATABASE.

Name	Description
Autoexec	Initializes system.
mcrChangeWindow	Changes forms.
mcrFind	Group of macros for finding specific records.
mcrForm	Manipulates forms including opening, closing, pagination.
mcrLaunch	Launches data to reports and word processing.

G. MODULES

The database uses four modules containing programs written in Access Basic (Table 9). The modules **modCaptionOnly** and **modChangeCaption** establish the appearance of the screen with the name of the database at the top. The module **modMoveRecord** permits the use of certain buttons on forms to move between records. Finally, **modUtilities** is a general set of utilities used in the databases.

TABLE 9. MODULES IN AEROSOL DATABASE.

Name	Description
modCaptionOnly	Sets up window to eliminate menus, tool bars, scroll bars.
modChangeCaption	Places caption on window.
modMoveRecord	Generalized routines for paging through records.
modUtilities	Contains assorted utilities.

SECTION V
RECOMMENDATIONS

The literature search and resultant database provide a valuable listing of references on aerosol technology as it applies to fire suppression applications. Every effort has been made to ensure completeness, however, new articles are being released regularly. It is recommended that articles be added to the database as they become available.

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AEROSOL DATABASE BIBLIOGRAPHY

This appendix includes a bibliographic citation for each document in the database. It was intended that the documents in this database include all available references to aerosol technology. Several references were discovered through online searches or in other documents. Consequently, there are several incomplete citations and a number of references do not contain abstracts. As these documents are obtained, the appropriate information will be entered into the AEROSOL Database.

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